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Airfield Passenger Transportation System at McMurdo Station, Antarctica

Peter M. Seman

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COVER: Aircraft passengers boarding Foremost Terra Bus at Pegasus Airfield for transit to McMurdo Station.

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Abstract:

The United States Antarctic Program's McMurdo Station in Antarctica is currently served by three airfields. Combined, these airfields are used for all passenger service and are a key element of the cargo supply system. The farthest of the sites lies approximately 16 miles from the main base on Ross Island, requiring travel across a glacial ice shelf. Travel time to this distant airfield currently takes 1 hour or more for passengers. The objective of this study was to explore the possibility of reducing this travel time by improving efficiencies in the McMurdo airfield passenger transportation system. With the sponsor's help, requirements for the system were identified, defined, and quantitatively scored for use in evaluating future alternatives. Safety, reliability, and travel time were the highest priorities. A site visit to observe current practices and interview key staff concentrated on three facets of passenger transport: roads, vehicles, and passenger management. Current routes, vehicle needs, and data recording practices were assessed. Recommendations are provided for action and further study.

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Preface

This report was prepared by Peter M. Seman, Force Projection and Sustainment Branch, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, NH.

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- Fleet Operations: Gerald Crist, Randy Knopik, Alan Shaw, and Frank Abbatecola.
- Vehicle Maintenance: Jim Story.
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The report was prepared under the general supervision of Dr. Edel R. Cortez, Force Projection and Sustainment Branch Chief; Dr. Justin B. Berman, Research and Engineering Division Chief; Dr. Lance D. Hansen, Deputy Director; and Dr. Robert E. Davis, Director, CRREL. The Commander and Executive Director of the ERDC is COL Kevin J. Wilson. The Director is Dr. Jeffery P. Holland.

Nomenclature

ATO	Antarctic Terminal Operations
CRREL	Cold Regions Research and Engineering Laboratory
ECW	Extreme Cold Weather [clothing]
ERDC	Engineer Research and Development Center
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GPS	Global Positioning System
NHTSA	National Highway Traffic Safety Administration
NSF	National Science Foundation
OSL	Outdoor Safety Lecture
PAX	Passenger
RPSC	Raytheon Polar Services Company
TBD	To Be Determined
USAP	United States Antarctic Program
WINFLY	Winter Fly-In

Unit Conversion Factors

Multiply	By	To Obtain
degrees Fahrenheit	$(F-32)/1.8$	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
tons (2,000 pounds, mass)	907.1847	kilograms
tons (2,000 pounds, mass) per square foot	9,764.856	kilograms per square meter

1 Introduction

Issue

The United States Antarctic Program's (USAP) McMurdo Station has traditionally been serviced by three airfields (Figure 1), used at different times during each field season (NSF 2006). A Sea Ice Runway is constructed each year in the harbor area adjacent to Ross Island. It accommodates both wheeled and ski aircraft: C-17, C-130, LC-130, and Twin Otter. On average it lies about 2 miles from the base. It is used from October to December before summer weather weakens the sea ice and the field must be abandoned. The Pegasus Runway, 16 miles from the station, is situated on the permanent glacial ice of the Ross Ice Shelf (Blaisdell et al. 1998). It can also support the same range of aircraft as the Sea Ice Runway, but is primarily used for wheeled intercontinental flights. It operates from December to the end of the summer field season in February. During August it is also used briefly to support WINFLY operations that prepare for the main season. Williams Field Skiway is the third, operating from December through February on the Ross Ice Shelf, and lies 8 miles from McMurdo Station. It is situated on snow and can only accommodate ski aircraft operations: the LC-130 and Twin Otter.

Productivity inefficiencies occur for a number of critical functions as a result of long travel times to and from the furthest airfields (Williams Field Skiway and Pegasus Runway). Cargo and passenger transport, as well as on-site workers and flight crews, can spend an hour or more traveling to or from the remote airfields. The travel time is a function of time of the year (primarily because of seasonal changes in road condition), the type of vehicles used, and the logistics of passenger handling. The focus of this study was to explore alternatives to the current systems that might be implemented by the USAP to realize significant travel time savings.

Objectives and Approach

The first objective was to work with USAP to identify and explicitly define the key performance requirements of the airfield passenger transportation system, and then quantitatively determine their importance. A weighting system was implemented to rank the requirements, allowing the organization's own values to be taken into consideration in the scoring of

proposed changes. The second objective was to provide feedback to the USAP on current operations and make recommendations for further action.

The process began by identifying the problem clearly and deciding on the scope of the study. Next, a brainstorming exercise was done to identify any factors that may affect the transportation process. These factors were divided into groups based on major themes. The themes were then clearly described and defined as the system requirements. With sponsor participation, the requirements were prioritized and preliminary metrics and goals were assigned to each.

Then, a site visit was carried out to gather information by observing current operations and gathering feedback from meetings with staff. The overall strategy for the trip was to focus on three general areas that affect travel time to the airfields: roads, vehicles, and passenger management (i.e., the logistics of handling, scheduling, etc.). Issues related to high priority performance requirements were given the most attention.

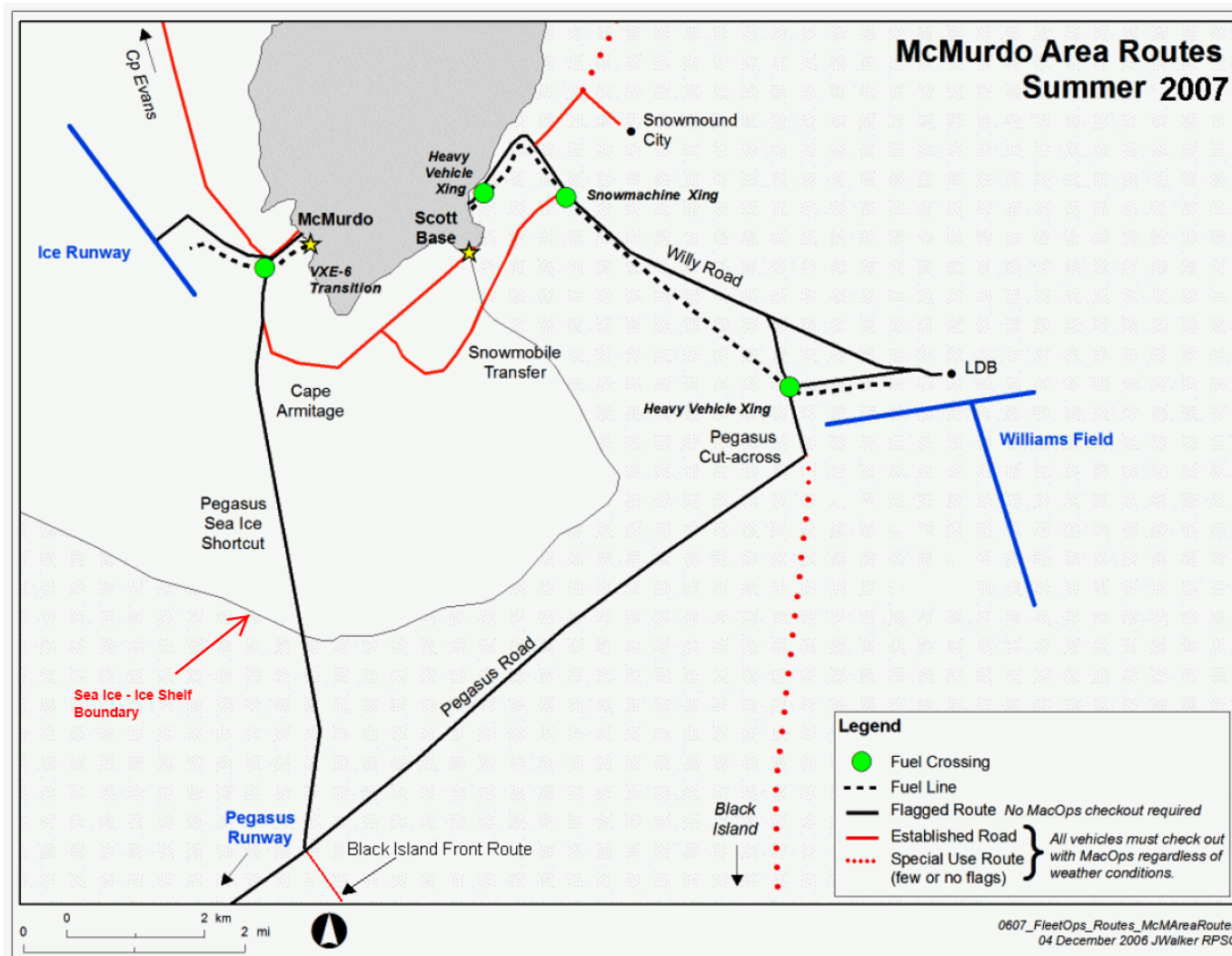


Figure 1. Airfields and snow road routes in the McMurdo Station vicinity.

2 Problem and Scope

A clear statement of the problem under consideration was confirmed with the USAP:

Travel time between McMurdo Station and Pegasus and Williams Field airfields is too long.

The primary focus was established as:

Identifying improvements that would benefit airplane passenger transport to the airfields.

Obviously, any gains that might be made towards this goal could provide secondary benefits in other areas. For instance, faster travel times would reduce the commuting time of shift workers to and from the airfields, freeing them to accomplish more tasks during the workday. Faster transportation could also free-up resources. Vehicles would be more available for alternative uses and might be allocated to transporting science parties, for example. Or, quicker transits could free-up drivers to work on other projects, such as cargo team members working on preparing pallets instead of spending as much time in the driver's seat.

Larger scope effects of consolidating airfields in the McMurdo area or decoupling the resupply of the South Pole Station from the McMurdo logistics chain were not considered in this study. While major structural changes like these would obviously have significant impacts on McMurdo operations, transportation from McMurdo to an outlying airfield will certainly remain a part of any future system. As such, increased efficiency gains within the current scope of work would be valuable, regardless of large-scale changes that may occur later. Similarly, improvements in the transportation infrastructure might lead to benefits for other functions, such as cargo movement. At the time of this study, attempting to consider the effects of all the complex interactions among the variety of operations and logistics functions at McMurdo seemed impractical and unwise. Thus, passenger transportation efficiency was treated as an isolated sub-system in this effort.

3 Defining System Requirements

Identification

After the problem was clarified, key factors that play a role in airfield passenger transportation at McMurdo Station were identified. A long list of issues associated with this function was assembled, and then grouped into similar categories. An attempt was made to separate these issues along lines that were as independent as possible from one another. Although some issues are difficult to separate completely, it was a useful exercise to clarify major themes among all the factors involved. Also, separating issues into mostly independent areas should provide a benefit in evaluating any future proposed changes or comparing alternative solutions. With this approach, the effects on each area can be considered individually in a clear and rational manner. While many issues that were identified could arguably fall into several categories, a primary category was selected for each. In a few cases, different facets of the same issue were split among multiple categories (e.g., energy use has both an economic and environmental cost).

Issues associated with passenger transportation clustered into the following nine themes, and a brief clarification is given for each:

- *Safety*: Operation of passenger transportation to avoid accidents, especially those with potential for causing personal injury.
- *Network Reliability*: Resiliency of the system to remain available for use.
- *Travel Time*: Passenger waiting time while in transit from origin to destination.
- *Environmental*: Impacts on the McMurdo environment.
- *Flexibility*: The degree to which the elements of the system can adapt to changes or provide assets with utility other than the airfield passenger transport function.
- *Passenger Comfort*: Comfort of vehicle occupants in transit.
- *Cost*: Overall fixed and operating costs during the system lifetime.
- *Implementation Time*: Lead time in implementing changes.
- *Legacy*: Impact of existing assets and practices on implementing changes.

In the sections that follow, each of these nine areas is described in further detail. For each major theme, the issues that play a role are highlighted and discussed. In some cases, the major themes actually depend on these subordinate items. In others, they're meant to convey the general nature that the area encompasses.

Safety

Passenger safety is a key emphasis of all transportation systems in general. The remoteness and harsh conditions on the Antarctic continent put a premium on safety for all USAP activities. Vehicle features and operation, plus road design, contribute to this area:

Vehicle characteristics

- “Sure-footed” over the terrain that they travel and the range of conditions that may be encountered.
- Ride shock and vibration.

Safety features and equipment in vehicles, including

- “Fail safe” or redundancy in critical systems (e.g., braking and steering).
- Emergency exits.
- Passenger ingress/egress in both routine operations and emergencies, especially wearing bulky Extreme Cold Weather (ECW) gear.
- Seat belts.
- Direct and robust communication link between driver and passengers.
- Fire extinguishers.

Safe vehicle operation

- Speed limit that is appropriate to the vehicle, terrain, and conditions.
- Visibility—the ability to both see and be seen by others.
- Navigation—flagged routes, GPS, radar, etc.

Road design

- Layout and grades.
- Safety features (e.g., guardrails).
- Visibility.

Network reliability

For transportation to be available when needed, the elements of the system must be reliable themselves and also be able to cope with challenging conditions that can lead to denied access. Some characteristics that contribute to overall system reliability:

- Incidence of mechanical breakdowns (vehicle failures).
- Cold weather performance and operating temperature range.
- Vehicle standardization and redundancy.
- Incidence of immobilization attributable to terrain (e.g., warm weather, drifting snow).
- Denial of access for certain vehicles because of road strength.
- Navigation and visibility issues.

Travel time

Many factors play a role in the amount of time it takes passengers to travel between McMurdo Station and the airfields. The length of travel time depends on variables such as:

- Distance traveled, which in turn is dictated by the origin and destination points and the route chosen between the two.
- Transfers of passengers from one vehicle or transport mode to another during the course of the trip.
- Pickup and drop-off stops.
- Vehicle top speed.
- Road conditions, including the effects of storms and warm weather.
- Capacity of the roadway to handle anticipated demand (e.g., narrow roadway sections can necessitate yielding to other vehicles).
- Effect of construction and maintenance activities on the passage of vehicles.
- Safe speed limit for passengers.
- Prudent speed limit for preservation of the road surface.

Environmental

Issues that affect the environment have an increased importance at McMurdo owing to Antarctic Treaty provisions. Some factors that play a part include:

- Energy use (number of trips and efficiency of vehicles).
- Vehicle emissions.
- Spills.
- Choice of fuel, including alternatives and renewables.

Flexibility

The ability of the system as a whole to adapt to changing conditions and needs is desirable, especially in a remote location with a harsh environment. The possibility of having system elements that provide capabilities and utility beyond their immediate function is another aspect of flexibility. Some issues that play a role in this area include:

Vehicles

- Capability to navigate different types of terrain (snow/ice, land, water).
- Use for alternative purposes beyond airfield passenger transport.
- Modularity of vehicle elements (e.g., a “train” system approach).
- Diversity of vehicle types that allow access under different conditions.

Road system

- Roads serve other purposes beyond airfield passenger transit.
- Necessary maintenance equipment useful or shared for other work.

Overall

- Ability to adapt to stressors related to climate change.
- Ability to accommodate fundamental system changes in the overall logistics program (e.g., a single airfield or different airplanes).

Passenger comfort

Comfort of the vehicle occupants while in transit is an important consideration that can affect not only the well being of passengers but has a small effect on system efficiency. It can create perceptions by regular users of how long the travel time “seems” to take, as well as projecting the first impression of on-ice facilities to McMurdo visitors. Faster loading and unloading of people and personal belongings can save some overall transit time. Comfort may also determine how receptive the population will be to system changes that are instituted.

Characteristics that contribute to passenger comfort include:

- Climate control, especially with ECW gear.
- Interior space, especially with bulky ECW gear.
- Ride smoothness.
- Noise in the passenger compartment.
- Loading and unloading efficiency and safety.
- Windows.
- Personal baggage space.
- Communication with driver.

Cost

Some factors that influence the overall costs of the passenger transportation system include:

- Impact of extreme climate on “traditional” forms of transportation equipment available in the commercial marketplace.
- Frequency of vehicle maintenance.
- Road network construction and maintenance costs.
- Energy use.
- Vehicle purchase costs.
- Vehicle lifespan.
- User cost of increased travel time or denied access.
- Vehicle utility loss due to increased travel time or denied access.
- Effect of traffic on construction and maintenance activities (number of vehicle passes, speed of travel, etc.).
- Idling time for vehicles.
- Influence of vehicle capacity on the ratio of drivers to passengers.

Implementation time

The lead time required to implement system changes can play a role in selecting alternatives suited to the available timeframe. Issues that influence this area include:

- Development, testing, and evaluating new technologies, especially for harsh polar conditions.
- Technology transfer and training for logistics support contractor.
- Procurement planning.
- Transition time for phasing in new equipment.

Legacy

Existing assets and practices can have an effect on implementing changes to the system. The institutional “inertia” of current infrastructure (e.g., vehicle fleet, road network) and established procedures (e.g., road maintenance, passenger handling and scheduling, etc.) may affect how alternatives with differing degrees of change to the status quo compare. In some sense each one of the vehicle fleet, road network, and passenger management areas dictate what is practical in the other two.

Prioritization and Goals

To most effectively utilize the system requirement areas identified above, they were prioritized and weighted with USAP input for two main reasons.

First, it is critically important to capture the values of an organization in this process. Prompting decision makers to reflect on competing issues and make deliberate choices among them is a very helpful exercise. This elicitation process helps make sure that the principles important to USAP are built into the decision making process.

Second, prioritization establishes the relative importance of different performance requirements. This helps when comparing alternative solutions in a decision matrix because the performance areas can be weighted differently. In this sense, when the alternatives are scored against each other, the results reflect organizational values. Establishing relative weighting also helps to focus energy most closely on the areas of greatest importance, producing the greatest payback.

Based on direct USAP input, the nine identified areas of system requirements were qualitatively grouped into high, medium, and low priority levels. Then, the requirements were weighted quantitatively on a scale of 1 to 10, with higher numbers representing greater priority (Table 1).

Table 1. Prioritization of requirements for McMurdo airfield passenger transportation system.

Requirement	Relative Weighting	Priority Level
Safety	10	High
Network Reliability	9	
Travel Time	8	
Environmental	7	Medium

Requirement	Relative Weighting	Priority Level
Flexibility	6	
Passenger Comfort	5	
Cost	4	Low
Implementation Time	3	
Legacy	1	

In meeting with the USAP to prioritize system requirements, some preliminary metrics and targets were identified. These are presented in Table 2 and Table 3. Though not identified as a performance requirement per se, “number of persons moved” was also included as a key metric for the system. For most of the performance targets, we tried to establish two levels for each area: a threshold representing the “minimum acceptable” and the “goal” representing an ideal where the point of diminishing returns has been reached. In some cases, only a single target was identified and no further distinction made. Because these metrics and targets are only initial ideas, refinement is needed before using these to score and compare alternative solutions.

Table 2. Possible metrics for the McMurdo airfield passenger transportation system requirements.

Requirement	Metric
Safety	Established standards for commercial passenger movement (NHTSA 2003). Look carefully at employing any nonstandard practices and justify departures from standards.
Network Reliability	Matrix of vulnerabilities, and how these can be addressed with system flexibility.
Travel Time	McMurdo Station to Pegasus Airfield.
Environmental	<ul style="list-style-type: none"> • Matrix for spills, byproducts, etc. • Emissions (quantitative). • Alternative fuel solutions.
Flexibility	<ul style="list-style-type: none"> • Ability to multitask. • Surge capacity.
Passenger Comfort	Average absorbed power (Pradko and Lee 1966).
Cost	$(\text{System Cost} \times \text{Travel Time}) / \text{Passenger}$.
Implementation Time	Years.
Legacy	<ul style="list-style-type: none"> • Life cycle cost. • Staffing.
Number of Persons Moved	Itself or combined with others into a composite metric (TBD).

Table 3. Suggestions for target performance levels of the McMurdo airfield passenger transportation system requirements.

Requirement		Minimum Acceptable	Goal
Safety		Meet established standards.	Exceed established standards.
Network Reliability		99% probability of one or fewer breakdowns per season causing more than a 1-hour delay.	
Travel Time		< 1 hour.	30 minutes.
Environmental	Spills	Maximize secondary containment.	
	Emissions	Meet current EPA commercial over the road standards.	Exceed current EPA commercial over the road standards.
Flexibility	Multitask Ability	Able to transport passengers and cargo efficiently to airfields.	<ul style="list-style-type: none"> • Able to transport wide range of cargo types to any regional location. • Prime mover able to support station operation functions.
	Surge Capacity	Accommodate one time 150% C-17 passenger movement (200 PAX).	Accommodate one time 200% C-17 passenger movement (270 PAX).
Passenger Comfort		School bus equivalent.	Commercial passenger bus equivalent.
Cost		Equal to current.	50% reduction.
Implementation Time		Fully operational the second Austral summer season after funding implementation phase.	
Legacy		Equal to accurate estimates of current baselines for lifecycle cost and staffing.	Better than accurate estimates of current baselines for lifecycle cost and staffing.
Number of Persons Moved		Guaranteed system capacity to meet all transport goals for predictable conditions.	

4 Site Visit

Approach

A site visit to McMurdo Station was carried out over the period of 15–25 January 2008 to gather information by observing the current system firsthand and meeting directly with staff engaged in their day-to-day operations. The overall strategy was to look at the passenger transport system from three points of view. The three major interconnected elements that impact travel time to the airfields were considered to be roads, vehicles, and passenger management (i.e., the logistics of handling, scheduling, etc.). Also, issues related to the high priority performance areas—safety, reliability, and travel time—received the most attention.

Given this framework, the Fleet Operations, Vehicle Maintenance, and Antarctic Terminal Operations (ATO) departments were the main focal points of the visit. After meeting with the senior NSF representative at McMurdo to confirm this approach, we began a three-step process. First, an in-brief meeting was carried out with the leadership in each department to familiarize them with the goals of the project, learn about the department's functions, identify their concerns and problem areas with passenger transport, and plan for field inspections. Second, a full day or two were dedicated to observing infrastructure and operations with each department, mostly touring with key staff while interviewing people during their work shifts. Finally, a closeout meeting was held with the leadership of each department several days before leaving McMurdo to clarify questions that arose from the field observations and interviews, to identify and discuss any further investigations to be made, and to provide preliminary impressions and feedback on operations.

Observations

Routes

All-season routes from McMurdo Station to the outlying airfields have been optimized according to the fixed constraints that exist on site. They are essentially configured in their current state because of the following factors:

- *Ross Island Topography.* The locations on the Hut Point Peninsula (Figure 2) where slopes and conditions are acceptable to approach the ice from the land or vice-versa are very limited. Transitions do exist in areas other than the one currently used at Scott Base (Figure 3). The VXE-6 transition (Figure 1) is used to access the Sea Ice Runway. Cape Armitage, formed by the flanks of Observation Hill, also has a transition on the eastern side that has been used historically (Figure 3). However, both of these points access the sea ice, which degrades as weather warms, and thus are not available for use throughout the entire summer season. Another transition exists where the Castle Rock Recreational Loop crosses from Ross Island to the Ice Shelf, but it traverses several miles of permanent snowfields on the peninsula and would add more than 5 miles to the current routes (Figure 2).
- *Ice conditions.* Current road routes on the ice are already optimized in terms of avoidance of pressure ridges near Scott Base and skirting as close as reasonably possible to the edge of the ice shelf on the way to Williams Field and Pegasus.
- *Distance.* Scott Base is the closest permanent ice shelf location to McMurdo Station.

These factors combine to limit the only practical all-season access point to the land from the ice shelf to its current location at the Scott Base Transition. Thus, the shortest viable routes to the outlying airfields are more or less fixed by geography and cannot be optimized further.

The route to Pegasus Airfield available throughout the summer season measures 15.9 miles from the McMurdo Station core (Movement Control Center, Building 140). A small part of this route—the “Scott Base Road” between McMurdo and the Scott Base Transition—is on the gravel roads of Ross Island (Figure 3). This portion of the route covers a distance of 2.1 miles, climbing gradually (2% grade) up out of McMurdo Station to the north side of Observation Hill, climbing again (8% grade) to its highest point northwest of Scott Base then descending quite steeply (up to a 15% grade) at times while negotiating several sharp turns before reaching the base and the transition¹. The remaining 13.8 miles to Pegasus is on the snow roads across the flat Ross Ice Shelf. From Scott Base Transition, the route follows the Williams Field Road, to the Pegasus Cut-Across, and the Pegasus Road itself before reaching the Pegasus Runway (Figure 1).

¹ Grades were determined in conjunction with a concurrent CRREL study of drainage and erosion control at McMurdo (personal communication with R. Affleck, CRREL).

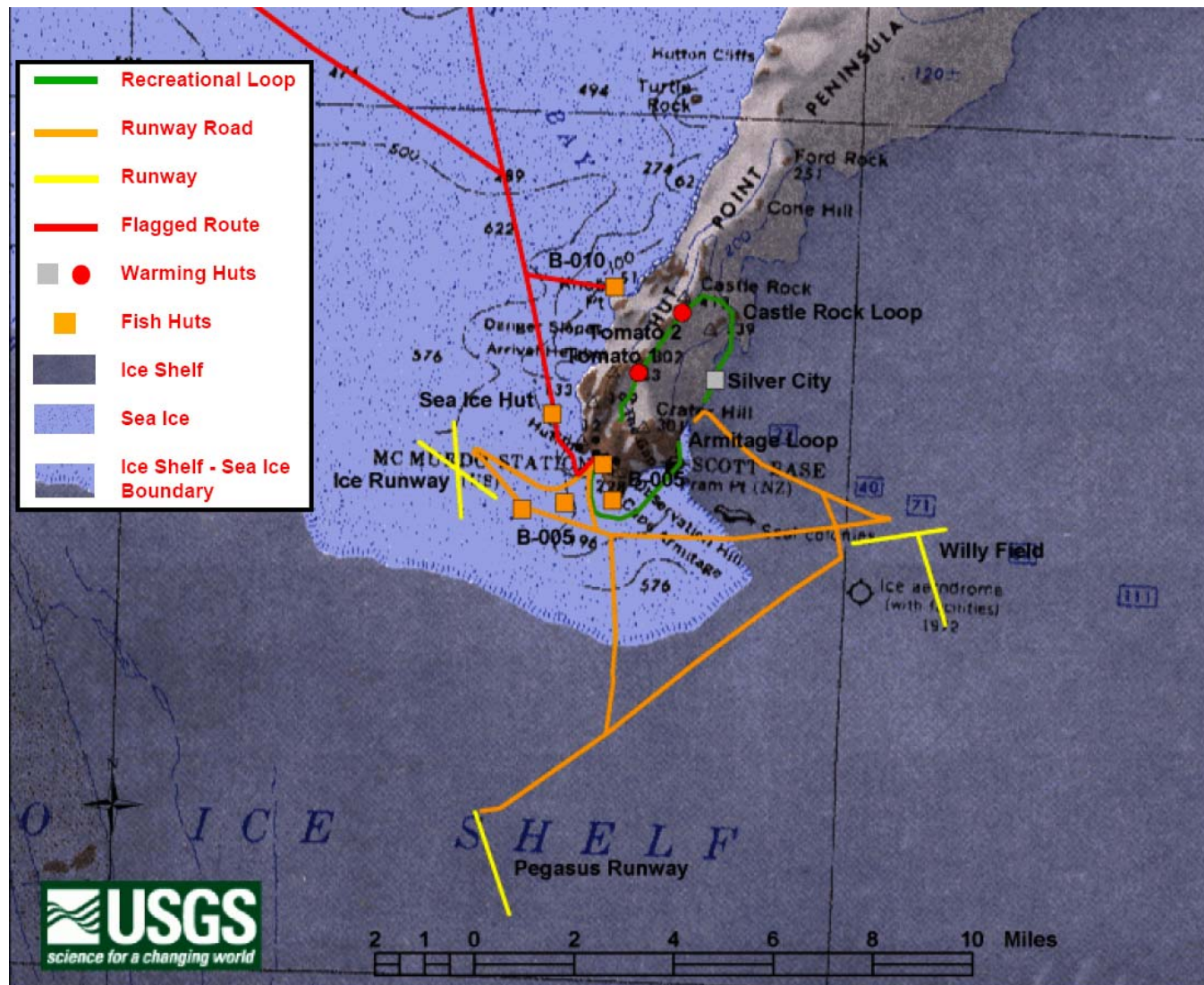


Figure 2. Hut Point Peninsula area with Castle Rock recreational loop route (green).

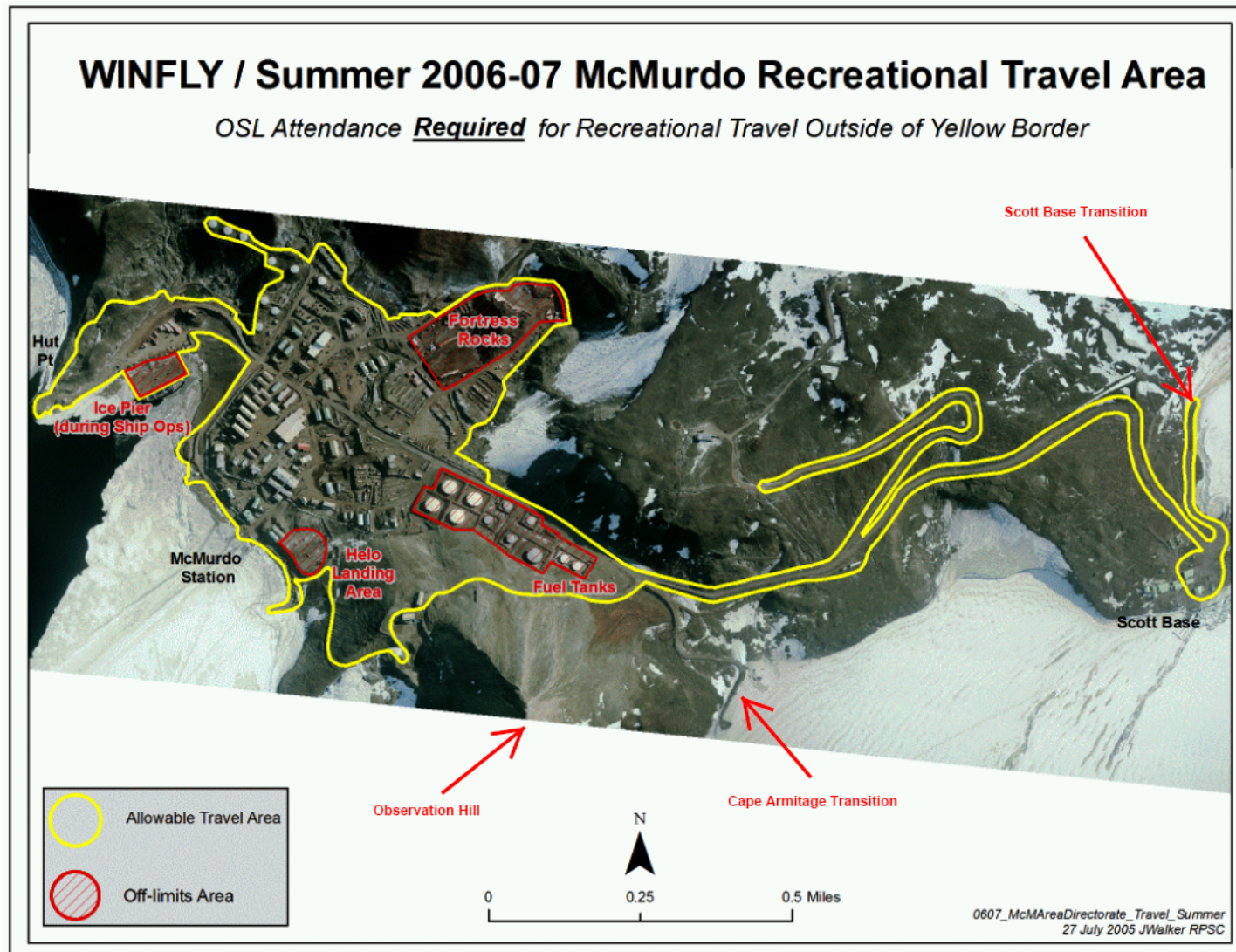


Figure 3. Scott Base Road from McMurdo Station (left) to Scott Base Transition (right).

Scott Base Transition

Scott Base Transition (Figure 4) is a weak link in the system, but a year-round transition is constrained to the current location. Therefore, any ground vehicle solution to the problem must negotiate the transition to get from the station to the outlying airfields and, thus, face any of the associated problems. This area can cause major operational difficulties when the surface softens during warm weather, or water drainage from the nearby cliff face causes ponding near the site (Figure 5).



Figure 4. Overview of Scott Base Transition with convergence of four snow road lanes. Note passenger Delta (left) for scale.



Figure 5. Flooded Scott Base Transition with cliff face (right), from ice shelf looking towards entrance from Ross Island, December 2007 (courtesy Fleet Operations).

Given its central role in the current system and any likely future alternatives, a detailed knowledge of the existing subsurface conditions at Scott Base Transition is critical to its conservation. The lack of subsurface understanding of the Scott Base Transition is troubling. For example, draining of water ponding at transition by drilling through the ice² brings questions. Where is the water going? Is it undermining the current transition, which could lead to future failure? For instance, if there are porous horizontal layers buried in the transition from natural processes or past maintenance activities, the water may be draining down these seams and destabilizing the entire transition. Without knowledge of the underground and underwater features at the site, it is impossible to know the answers to these and other questions. A monitoring program to record weather conditions in the area and ice temperatures with depth (as was done during the development of Pegasus) could be helpful in gaining further insights.

Current passenger vehicles

A variety of vehicles are currently used at McMurdo for transporting passengers to the airfields (Figure 6). Wheeled vehicles are generally used. One tracked

² Drilling was the method used to drain the transition in December 2007 (personal communication with Gerald Crist, Fleet Operations).

vehicle is available, though it is only rarely used when road conditions dramatically deteriorate.

During the site visit, all passenger movement to the airfields happened with wheeled vehicles. There are four wheeled vehicle types in the current McMurdo fleet that have sufficient seating capacity for regular passenger transport. These include:

- Ford E350 4×4 passenger van equipped with 40-in. flotation tires. Accommodates up to 12 passengers (six available).
- Ford E350 “Airport shuttle style” van equipped with 40 in. floatation tires. Accommodates up to 20 passengers (two available).
- Foremost Delta 4×4, passenger version, with 66-in. low ground pressure tires. Accommodates up to 25 passengers (three available).
- Foremost Terra Bus 6×6 with 66-in. low ground pressure tires. Accommodates up to 56 passengers (one available).

The tracked vehicle is a Foremost CF 110, passenger version. There is only one available and its passenger compartment is identical to the Delta’s with a carrying capacity of 25. I did not observe this vehicle in operation during the visit.

Both the wheeled and tracked Foremost vehicles operate at lower ground pressures and thus can be used throughout the summer field season, even when snow roads become soft in warm weather. The vans impose higher loads on the road surface and may be restricted or banned to avoid road damage or vehicle immobilization when these conditions occur.

The Terra Bus and Deltas are primary means to transport passengers for bulk movements (i.e., intercontinental flights), while the E350 4×4 vans play only a supplemental role. No airport shuttle vans were in use for these movements.



a. E350 van.



b. E350 "airport shuttle style" van.



c. Delta.



d. Terra Bus.



e. Foremost CF 110.

Figure 6. Vehicles used for airfield passenger transport.

Vehicle speed

During the site visit from 15–25 January 2008, trips taken to the airfields on the Terra Bus and the Deltas indicated that their average speed was approximately 10 mph on land and about 20 mph on the snow roads. These combined speeds result in an overall transit time in the range of 50 to 60 minutes to Pegasus from McMurdo, which agrees with observations of several round trips. It seems reasonable to consider this as typical of current operations for periods when the snow roads are firm and in good condition. Vans traveled somewhat faster on land (typically 15–20 mph) and kept closer to the 25 mph speed limit on snow. This made van travel time to Pegasus slightly faster, approximately 40 to 45 minutes. When mass movements to the airfield were made, the TerraBus generally traveled in a convoy with one or more Deltas. This may play a partial role in their lower speeds relative to a single van, but vehicle characteristics probably have an influence as well.



Figure 7. Melted condition of Scott Base Transition on 20 January 2008.

At the time of the site visit, the Scott Base Transition was melting and deteriorated (Figure 7); however, the light vehicle fleet of passenger vans and pickups could generally negotiate it slowly without becoming immobilized. The

transition presented no problem to the Deltas and Terra Bus. At times when conditions are worse, depending on the weather and type of vehicles required to traverse the route, it was reported that travel times to Pegasus can easily extend to 2 hours and sometimes as much as 3 owing to the need to travel slowly or use tracked vehicles.

With the constraint of a fixed route to Pegasus Airfield via Scott Base Transition, the required surface vehicle speeds can be explored for different travel times from McMurdo Station. The tradeoff between vehicle speed on land and on the ice shelf is illustrated in Figure 8 for a series of different overall travel times ranging from 20 to 60 minutes. At travel times of 50 and 60 minutes, the benefit of land speeds above the current 10 mph is relatively small. Likewise, land speeds above 15 mph are not very beneficial when travel time is 40 minutes. However, when the travel time drops to the 30 minute target time, the sensitivity of the necessary ice shelf speed to land speed becomes more significant at land speeds up to 20 mph or more. Overall travel time of 20 minutes requires ice shelf speeds of 55 to 60 mph for the range of land speeds considered here. As such high speeds on the ice shelf would seem to be out of reach at this time, this curve is presented mainly as an illustration of an upper bound on the current problem.

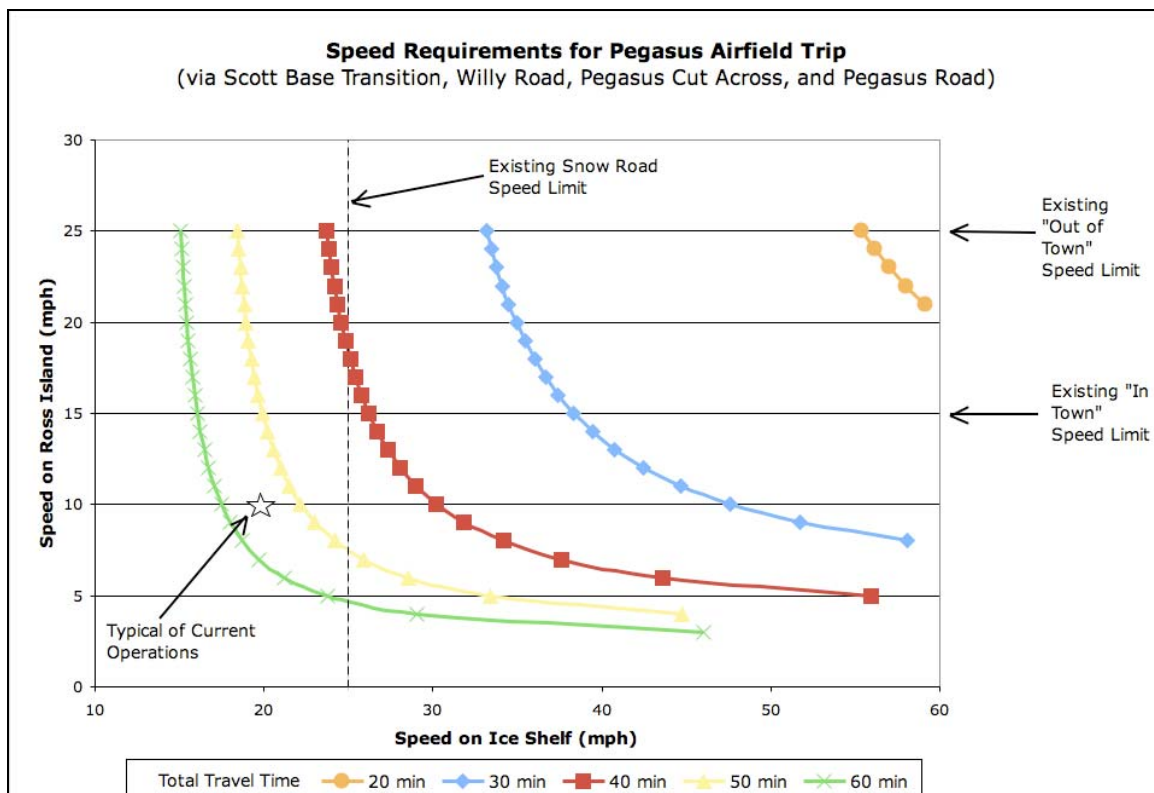


Figure 8. Surface vehicle speed requirements for travel to Pegasus Airfield from McMurdo Station based on total transit time.

To move from the current typical transit time indicated in Figure 8 towards the 30-minute goal, both the average land speed³ and the maximum ice speed need to be increased. Current landside speed limits are 15 mph within the confines of McMurdo Station and 25 mph beyond “town limits” for safety reasons. In town, speeds must be kept low because of frequent vehicle and equipment traffic, a dense network of road intersections around the buildings and cargo areas, and pedestrian traffic sharing the roadways with vehicles. The speed limit outside of town is higher because there is a general lack of the in-town factors; it is primarily dictated by topography and road layout. The Scott Base Road in particular has several steep grades and sharp curves just above Scott Base that cannot be negotiated safely at high speed, especially with its lack of guardrail protection. Thus, landside speed limits are set at a prudent level and should be maintained at or very near their current values for safety.

The installation of guardrails on the Scott Base Road should be seriously considered. Two locations deserve particular attention. A steeply graded section oriented from northwest to southeast leads down to the Scott Base (at far right in Figure 3). The road shoulder’s northeast slope is very steep leading down to the Scott Base Transition area and includes a fuel line route going to the airfields. Previously, this area was the site of an accident where the tracked Foremost CF 110 went over the hill and was stopped only by a fuel line support. In this instance injuries were minor but the results could have easily turned out very differently, especially with the additional risk of the fuel source. The second portion to consider is further west, approximately 0.25 mile beyond a sharp left hand turn at the top of the first section (when traveling from Scott Base towards McMurdo). This second road section is generally oriented east–west and skirts the shoreline closely, with a southern shoulder leading down the steep slope to the ice. Guardrails at both sites would allow vehicles to travel safely at speeds closer to the current posted limit, while increasing overall safety in general at any speed. There are several operational issues that must be addressed to determine whether this is a practical approach. Guard rails could pose problems with snow drifting and subsequent snow clearing around them. Also, installing guard rail pilings into the frozen ground and maintaining a straight alignment from season to season could be a challenge. The performance of the airfield fuel line design should provide some insight. Finally, choosing guardrails that will work for heavy, high profile vehicles, such as the Deltas and other construction equipment, could be difficult.

³ Average landside speed achieved in practice, not the speed limit. Likewise for ice speed.

Given the 10-mph average speeds on the gravel roads that were observed during the visit, there's room for speed improvements on land to bring actual speeds closer to the posted limits. To allow an ice shelf speed in a range that may be achievable (perhaps 35 to 40 mph), land speeds must be on the order of 20 to 15 mph respectively to get to Pegasus in 30 minutes. Land speed must also be a consideration when evaluating prospective vehicle solutions for the transit system. When selecting vehicles for increased speeds on the ice shelf, landside speed can't be compromised too much without making the overall goal of 30 minutes difficult to achieve.

Some minor improvements in the maintenance of the current gravel roads could help improve land speeds. During the visit, there were two washouts along the road between McMurdo and Scott Base, both of which caused vehicles to slow considerably when crossing. One washout was at the intersection with the road leading up to Observation Hill (Figure 9, left). The second washout was on the McMurdo side of the height of land on the Scott Base Road (Figure 9, right). In both cases, provisions for basic road drainage (i.e., culvert pipes) were either completely absent (former case) or non-functional (latter). The lower end of two culvert pipes were present at the second washout site but the upper ends could not be located and no water was draining through them at the time, despite thawing conditions. Ice blockages make maintaining open culvert pipes especially difficult in cold regions. However, more basic attention to maintaining existing drainage resources and installing ditches and properly-sized culverts in areas that currently lack them should help keep traffic running smoothly at higher rates of speed.

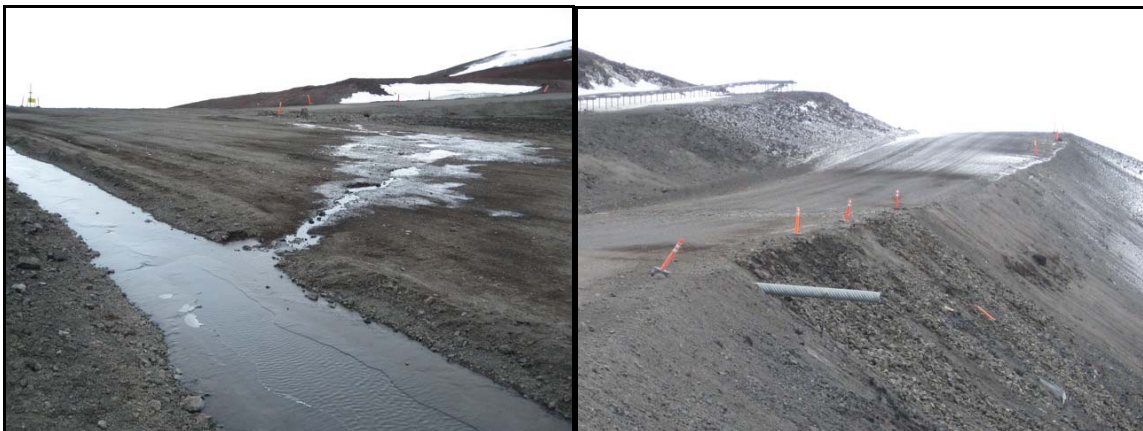


Figure 9. Washouts on Scott Base Road.

Vehicle speed limits on the ice should be looked at more closely as well. During times that the roads are in good condition and visibility is not limited, it seems

feasible to allow speeds greater than 25 mph. Fleet operations personnel indicated that road conditions are typically most troublesome (from a maintenance standpoint) between mid-November and mid-January. The transportation system runs at maximum capacity earlier and later in the season; therefore, an increase in speed limit during the “shoulder season” would provide improved transit times when the greatest number of people is riding. Fleet operations personnel responsible for road maintenance did not see a problem with traveling at higher speeds (conditions permitting). For example, they suggested that up to 40–50 mph in a pickup truck on a clear day when roads are relatively firm would cause little distress to the road surface. At this speed stopping distance should not be a safety issue, given the extremely long sight distances, but for lower visibility periods (blowing snow, fog, etc.) speed would need to be reduced.

Unfortunately, taking advantage of road conditions that allow higher speed is not possible with the Deltas and Terra Bus currently used for the majority of airfield passenger movements. These vehicles are only capable of top speeds of approximately 25 mph.

One issue with allowing higher speeds at certain times could be getting drivers to comply with lower speed limits during periods when roads become soft. A system of stricter enforcement could be necessary, perhaps with loss or restriction of driving privileges for repeat offenders. Implementing both policies at once might help with receptiveness, communicating to drivers a new benefit (higher speeds at times) and new penalties for speed limit violations. Policing to enforce the speed limits is impractical, but fostering a community approach where drivers remind each other if they observe excessive speed could help. Alternatively, technology solutions used to record travel time could also be used to check for compliance with speed limits. Or, commonly available portable radar speed trailers (Figure 10) could help provide feedback for self-enforcement. In any case, efforts to better communicate the speed limit in effect would be necessary—with better signage at lane entrances and perhaps including the speed limit in the current weather condition reports.

A final issue that concerns human factors and vehicle speed is driver experience. Efforts to retain or recruit drivers familiar with the vehicles and conditions at McMurdo could result in faster travel times without any investment in vehicle or road improvements. During the visit, anecdotes revealed that, under certain conditions, an experienced driver could reach Williams Field in half the time as a less experienced one driving under the same circumstances. Collection of travel

time data should allow the type of analysis to determine if travel time really is correlated with driver experience and deserves attention.



Figure 10. Typical Portable Radar Speed Trailer (Source: FHWA).

Vehicle requirements

Finding a vehicle that will satisfy the diverse set of requirements for the program will be difficult. USAP has unique mission requirements, so the commercial market for these types of vehicles will most likely be very limited, and thus expensive. Challenging issues include:

- *Speed.* Options for fast (~40 mph) over-snow vehicles of any significant passenger capacity will be limited.
- *Terrain.* Separate ice shelf fleet and land fleet vehicles seem impractical. Finding versatile vehicles with reasonable purchase, operating, and maintenance costs that perform well on both land and snow environments could be a challenge.
- *Ride comfort.* Vehicles geared towards meeting other requirements may tend to come up short in this area or vice-versa (Figure 11). Passengers dressed in bulky and warm ECW gear present a unique challenge to interior space (Figure 12) and climate control considerations. Vehicles with separate passenger compartments may not have adequate shock and vibration damping for passengers, or the driver may not realize passenger shock and vibration issues.

- *Passenger capacity.* Finding appropriately sized vehicles for passengers at McMurdo that also meet speed and terrain requirements may be difficult.
- *Avoiding a custom solution.* Ideally, solutions should be as close to a “stock” vehicle as possible. Some minor retrofitting would be expected to meet polar environment demands. However, too much could lead to increased strain and maintenance issues and reluctance of manufacturers to provide ongoing support. Resale also becomes an issue the more specialized a vehicle becomes.
- *All condition.* Vehicles (or vehicle fleet mix taken as a whole) must be able to permit reliable access over a wide range of environmental conditions (melting, drifting snow, low visibility, etc.).
- *Safety systems.* It is preferable that critical items such as roll over protection, fail safe brakes, etc., be incorporated from the beginning. Aftermarket retrofits and in-house custom-made solutions should be avoided.



a. Delta



b. Terra Bus.



c. Airport shuttle style” van.

Figure 11. Range of comfort levels in vehicle passenger compartments. “



Figure 12. Overcrowded aisle in the Terra Bus due to ECW and hand carry bags.

Perhaps there may not be a single vehicle solution for the system, but one more along the lines of a “two-tiered” approach that is practiced currently. In this framework there is a “backbone” of robust vehicles (e.g., Terra Bus and Deltas) that are capable of handling any road condition, with the expectation that they may not be as speedy overall. These are supplemented by a more “opportunistic” class of vehicles (passenger vans) that can achieve the desired speeds when conditions are better. Newer, more reliable, and more comfortable “backbone” vehicles (which perhaps might be speedier too) and larger-sized “opportunist” vehicles could be considered as updates to make improvements over current operations. In terms of which vehicles can be used over the course of the austral summer, the state of the Scott Base Transition and snow roads are important. Surface conditions at the transition dictate which vehicle types can be used, while the time to cross the transition itself has very little influence on the overall trip time to the airfields, given its short distance (~100 to 200 yards). Preservation of the snow roads from vehicle damage in very warm weather also determines which vehicles can be used.

Another interesting concept involves the modularity of vehicle elements that decouple the power unit from the passenger units to provide a “plug and play”

system. Like adding passenger cars on a train, capacity could be increased or decreased to meet changing demand. Also, terrain specific (e.g., power) units could be switched when moving from land to ice, and individual units could be swapped out for maintenance without putting the whole vehicle out of service. While discussing this approach with staff at McMurdo, reactions generally appeared cool to the idea. This could be partly a “legacy” issue where established practices result in resistance to changes.

Some vehicle solutions were suggested during site visit meetings that have well-reasoned thinking behind them and deserve further consideration. These included the idea of a mid-size Terra Bus that would be able to hold 25 to 30 people. ATO staff thought this would provide a much better passenger to driver ratio than the passenger vans. They seem to prefer an all-terrain vehicle solution, and justifiably have concerns about the reliability of an aging Delta vehicle fleet. Heavy reliance on a single Terra Bus for all mass passenger movements and the aging Deltas when road conditions deteriorate do represent significant weaknesses in the current system. Vehicle Maintenance staff also like the Foremost wheeled vehicles (Deltas and Terra Bus) because experience shows they perform well, manufacturer support has been good, and their overall life-cycle costs are not unreasonable when compared to a customized solution. Fleet Operations staff also like the wheeled Foremost vehicles because of their low ground pressure. In fact, these vehicles appear to act as pneumatic rollers, actually improving the surface condition as they traffic the snow (Figure 13).

Another idea with merit was to include a mid-sized passenger vehicle in a coordinated acquisition program for the heavy vehicle fleet. As has been done with the Ford F350 and E350 series light vehicle fleet of trucks and vans at McMurdo, a common platform for heavy applications (e.g., tankers, dump trucks, cargo trucks, etc.) could include a passenger vehicle variant. Perhaps a “stretch” airport style shuttle would be feasible on such a platform outfitted with oversized floatation tires. Vehicle Maintenance staff have been pleased with the coordinated light-duty vehicle fleet approach in terms of common parts, mechanic training, operator familiarity, etc. Incorporating an airfield passenger transport vehicle as part of a coordinated heavy vehicle fleet could provide similar benefits and more reliable availability.



Figure 13. Delta tire path crossing over tracked and light vehicle tracks, resulting in improved road surface condition (cell phone shows scale).

Other application areas where vehicles must address similar demanding requirements in challenging environments could serve as candidates for “lessons learned” analyses. For example, military tanks and armored personnel carriers have several of the same requirements as McMurdo (i.e., simultaneously reliable, high speed, all terrain, safe, and comfortable). But, military vehicle development and manufacture is extremely expensive: it is the epitome of a custom solution. Even so, it may be worthwhile to consider if anything could be learned from the approach taken in a somewhat analogous transportation application. Perhaps there may be lessons learned in the development of the new South Pole Traverse capability that could also be considered. However, as that is geared toward the movement of fuel and cargo with lower time sensitivity, the overlap with an ideal system at McMurdo could be limited. Nevertheless, these are just two examples that might help to provide inspiration for vehicle solutions. Further brainstorm-

ing efforts would most likely yield many more special performance applications that could be “mined” for ideas.

Travel time records

To optimize the system for faster transit times, the transport time from origin to destination is a critical statistic. Shuttle operations (responsible for both airplane passenger movements and shift worker transportation) collect data in vehicle logs. The information recorded includes: origin, destination, departure time, number of passengers, Scott Base pickup and drop-offs, airplane passengers, vehicle (fleet) number, driver name, and remarks. Unfortunately, arrival times are not recorded and thus travel time cannot be determined. During the site visit, I prompted the ATO shuttle supervisor to add arrival time to the vehicle log sheets, so some data may be available in the near future that could be analyzed. The relationship of travel time to weather conditions, driver experience, vehicle type, and other parameters should be explored to look for patterns. These data could lead to new realizations or be used to test existing assumptions.

Upon reviewing a sample log sheet for a regularly scheduled shuttle service to Williams Field (not associated with passenger transportation for flights), the departure times recorded always corresponded exactly with the published schedule. This may demonstrate a perfect record of on-time service; however, it could also indicate that the recording of these times is only approximately correct. Thus, having drivers record departure and arrival times themselves may not be effective. The limited accuracy would have major implications for the usefulness of the data for analysis. The vehicle log data are compiled in spreadsheets to provide electronic summary reports (weekly and seasonal), but not all detail is captured (i.e., granularity decreases). Based on the existing methods for capturing information, a significantly increased data entry effort would be necessary to do the types of analyses envisioned.

Given the time and accuracy concerns of self reporting of travel time and the data entry effort associated with paper logs, an automated system could provide a more attractive alternative. Inexpensive GPS navigation systems and fleet tracking are commonplace in the U.S., so it seems reasonable that a system could be fielded economically. Location and vehicle data could be recorded automatically, while other data could be entered by drivers via keypad or touchscreen. Older vehicles can probably accommodate such devices with little or no retrofitting, but would lack the ability to provide vehicle data from the onboard computer’s sensors. This information is commonly available in vehicles from the mid-

1990s and newer. Data collection and vehicle tracking could also help with ATO planning, search and rescue, and perhaps vehicle maintenance if integrated with a fleet management type system. An automated data collection system for the vehicle fleet should be considered. Based on this recommendation, a follow-on study is exploring the use of GPS trackers in vehicles during the 2009-2010 field season (Knuth and Shoop 2010).

Sustainability

Infrastructure solutions must be in harmony with the environment to be sustainable for the long term. This is especially true in a harsh climate, where highly constrained resources cannot sustain a “brute force” approach. A good example of this philosophy in action was the choice of the Pegasus runway site on the edge of a snow ablation zone (Mellor 1988). This location allows siting on the strong glacial ice that can support heavy wheeled traffic loads. But, it also provides proximity to enough fresh snow for covering the surface to protect it from melting by solar radiation in the warm season. Being in an area of minimal snow accumulation permits access to this critical resource, while keeping snow removal requirements to a minimum.

5 Summary and Recommendations

Nine performance requirements that play a role in transportation of passengers to the outlying airfields at McMurdo were identified during this study. In an interview with NSF staff, these were ranked in order of importance. The highest priorities for the system as a whole are safety, network reliability, and travel time. In identifying the areas and capturing organizational values, a framework is now available for evaluating the current system and alternatives. After refinement of the preliminary performance metrics and targets presented here, the follow on process of identifying promising solutions and weighing their tradeoffs can now begin.

Roads, vehicles, and passenger management at McMurdo are all a part in the process and each will play a role in the solution. Viable routes to the outlying airfields are more or less fixed by geography— island topography, ice conditions, and distance—and cannot be optimized further. The year round transition to the ice shelf is constrained to the existing location at Scott Base. Maintaining year round availability to all the existing vehicles in the fleet remains a difficulty for the current system. Exploring the contribution of vehicle speeds over both land and ice shelf to overall travel time provides a way to approach the issue. Observed vehicle speeds were much lower than set limits, providing room for improvement. Even if land speeds improve and meet the existing prudent speed limits, travel on the ice at 35 to 40 mph will be needed to achieve the 30 minute goal. Efforts to find a vehicle that satisfies this, along with road and passenger constraints, may prove difficult. Having the proposed scoring system should prove useful in the process. Other potential approaches that could have merit and deserve discussion include solutions not based on a single vehicle type, or incorporating the larger passenger transport vehicles into a coordinated heavy vehicle fleet.

Based on this assessment, the following items are recommended for further action:

- Record travel times for airfield transport, including regularly scheduled shuttle service. Explore available basic automated data collection systems for ATO shuttle, taxi, and airfield transport operations.
- Because of its key importance to the current system and practical future solutions, a better understanding of the Scott Base Transition area is prudent.

A subsurface investigation of the site is suggested to establish a better understanding of the inherent site characteristics.

- Survey the commercial vehicle market to identify candidate vehicle solutions that could satisfy the requirements identified in this report. Brainstorm analogous applications for “lessons learned” ideas.
- Identify and assess alternatives, including a cost/benefit analysis when possible and appropriate.
- Explore the feasibility of conditions-based speed limits for snow roads.
- Maintain current speed limits on land. Place further emphasis on maintenance and design of Scott Base Road drainage to help vehicles attain these speeds.
- Consider installation of guardrails or other safety features on Scott Base Road.

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14. ABSTRACT The United States Antarctic Program's McMurdo Station in Antarctica is currently served by three airfields. Combined, these airfields are used for all passenger service and are a key element of the cargo supply system. The farthest of the sites lies approximately 16 miles from the main base on Ross Island, requiring travel across a glacial ice shelf. Travel time to this distant airfield currently takes 1 hour or more for passengers. The objective of this study was to explore the possibility of reducing this travel time by improving efficiencies in the McMurdo airfield passenger transportation system. With the sponsor's help, requirements for the system were identified, defined, and quantitatively scored for use in evaluating future alternatives. Safety, reliability, and travel time were the highest priorities. A site visit to observe current practices and interview key staff concentrated on three facets of passenger transport: roads, vehicles, and passenger management. Current routes, vehicle needs, and data recording practices were assessed. Recommendations are provided for action and further study.					
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